AD-A284 932

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden ... per response, including the time for reviewing instructions, searching existing data sources, gathering and ... collection of information. Send comments regarding this burden estimate or any other aspect of this collection of ... Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway ... and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE 29 April 1994

3. REPORT TYPE AND DATES COVERED FINAL, SBIR N93-002, 10/93 - 03/94

4. TITLE AND SUBTITLE

Metadata Database for Automated Oceanographic imagery

5. FUNDING NUMBERS

C-N00014-93-C-0240

6. AUTHOR(S)

Pickett, Robert; Schatzle, Frank; Corbin, James
Krishnamagaru, Ramesh; Anantharaj, Valentine; Bridges, Susan; Hodges, Julia

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Gulf Weather Corporation and
MSU Center for Air Sea Technology
MTTC, Bldg. 1103
Stennis Space Center, MS 39529

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
ONR 4530 D, CDR. Peter De Vries, Scientific Officer
800 North Quincy St.
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

DTIC
ELECTE
SEP 22 1994
S G D

32 pg

94-30405

11. SUPPLEMENTARY NOTES

SBIR Phase I Final Report, Topic No. N93-002

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Report contains proprietary SBIR information.
Releasable as Unrestricted after decision and award of Phase II.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This is the final report on the exploratory research performed by Gulf Weather Corporation (GWC) and the Mississippi State University Center for Air Sea Technology (MSU CAST) on Phase I of SBIR topic N93-002; subject: Automated Oceanographic Imagery Information. The sponsor of the research was the Office of Naval Research.

Investigation revealed that the primary means of satellite imagery interpretation is by manual. The methodology is cumbersome and the number of "things of interest" is large, making it highly manpower intensive. The anticipated rapid increase in satellite systems and sensors and the increasing requirements for satellite remotely sensed data to support oceanographic and meteorological models and fleet support applications, particularly in the near-shore coastal zone, indicates that the situation will continue to worsen. The only long term solution is an integrated system of automated tools for satellite data interpretation. There are a number of automated satellite image analysis algorithms available today and others under development. This report provides the generic design for a metadata database system based on "object-oriented" software, that will provide the "user-friendly" system for making satellite data analysis tools available to Navy operational and research oceanographers and meteorologists.

14. SUBJECT TERMS

Metadata Database Automated Ocean Imagery

15. NUMBER OF PAGES 32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

TABLE OF CONTENTS

Accesion For

NTIS CRA&I ☒
DTIC TAB ☐
Unannounced ☐
Justification

By
Distribution /

Availability Codes

Dist	Avail and / or Special
A-1	

1.0 SUMMARY

This report describes the exploratory research performed by Gulf Weather Corporation (GWC) and Mississippi State University - Center for for Air and Sea Technology (CAST) under Phase I of the Department of Defense Small Business Innovation Research (SBIR) Program Solicitation 93.1, Department of the Navy Topic Title N93-002 Automated Oceanographic Imagery Information.

The long term objective of the project is to develop a unified information structure for a system for integrating a system of automated tools and methodology to efficiently provide its output to oceanographic forecast models. Phase I efforts were to be directed at developing recommendations for integrating a system of automated analysis tools in the most appropriate manner.

To fulfill this requirement, two major objectives were set for the Phase I efforts. The first objective dealt primarily with finding out what the Navy operational community interests were as far as features or systems derivable from satellite data, the primary satellite data being used by the community, the methodology used for satellite data feature recognition, and the present status of automated algorithm development for eventual inclusion in the system developed.

The second objective was to develop recommendations for a generic system for integrating automated analysis tools into a useful information structure in the most appropriate manner.

Objective One investigations determined the following:

- Primary means of analysis of oceanographic and meteorological satellite imagery today is manual. The list of "things of interest" in satellite data is extensive, the manual techniques are difficult to learn under the Navy short tour environment and do not lend themselves well to input into current forecast models.

- Primary satellite data used are thermal and visual data. Altimeter and scatterometer data are used to some extent at larger forecast centers. SAR is used primarily for ice information.

- Other satellite data such as high resolution visual/thermal and color scanner shows promise for future Navy use.

- There are a number of automated algorithms for recognizing meteorological and oceanographic features and systems in satellite data in existence or under development.
- The system developed should cover a wide range of users from the large production centers down the individual forecaster using a TESS-3 system or a research scientist using a personal computer, working with one automated algorithm in a limited area of interest. The system should be area transparent, accepting algorithms of a variety of types in any area of the globe.

Under Objective Two, we designed a generic metadata database system based on object oriented programming which will accept processed satellite imagery and interface it with a metadata database of automated interpretation algorithms to derive features of interest. The data is then processed through an intermediate query/applications module where it can be melded with other observation and analytical data to product a final feature/systems storage metadata database.

A demonstration metadata database system was developed and using an oceanographic four year database of analyzed North Atlantic fronts and eddies as an assumed output from an automated algorithm run through a series of queries/applications typical of what might be used by an operational oceanographer. Primary rationale for the demonstration was to provide proof of concept of the system and the ability of the GWC/CAST team to develop the end-to-end system required under Phase II.

The final conclusions were that the present system, primarily manual, is cumbersome and rapidly being overwhelmed by the volume of data and new requirements; the only practical solution is through the use of automated algorithms or systems for satellite data interpretation; and that a metadata database system such as that discussed in this report is required to make the automated algorithms operationally usable. The final recommendations were that the Navy program for automated algorithm development be continued and that the metadata database system for handling automated algorithms for satellite interpretation be developed.

INTRODUCTION

2.0 This report describes the exploratory development research performed under Phase I of the Department of Defense Small Business Innovation Research (SBIR) program solicitation 93.1, Department of the Navy Topic Title N93-002 Automated Oceanographic Imagery Information.

The long-term objective of the research and development set forth in the solicitation is to "Develop a unified information structure for a system of automated tools and methodology to provide its output to oceanographic forecast models efficiently." The effort designated for the Phase I research was to "Develop recommendations for integrating a system of automated analysis tools in the most appropriate manner."

SBIR Phase I research and development is concentrated on proving the scientific and technical feasibility of the proposed effort as a prerequisite for further support in Phase II. The objective set forth in the solicitation for Phase II is the "Development of a complete, end to end system (including assimilation into models) based on the recommendations that result from Phase I, and demonstrating and testing the system on data to be supplied by the Government."

Gulf Weather Corporation (GWC), a small business concern teamed with the Mississippi State University, Center for Air and Sea Technology (CAST) for this research and development project. Dr. Robert E. L. Pickett, Ph.D. Physical Oceanography, of GWC, was designated as the principal investigator. The proposal set forth by the GWC/CAST team was for the development of a metadata database system as the end-to-end system for handling automated tools for use in satellite imagery interpretation.

The long-term goal of the research and development is to provide Navy oceanographers and meteorologists with the tools needed to analyze image data along various dimensions of interest in a system consistent with their abstract concept of the information stored in the database. This requires that database technology be extended in ways that will allow scientists and operators to undertake investigations that would not be feasible without such tools. In order to accomplish this goal, those characteristics of the data they would like to use as a basis for queries must be identified. It will then be necessary to incorporate techniques to derive the desired information from existing data in the database. After this process of knowledge discovery, it is essential for the system to be able to store and manage the derived information and also to extract the primary data, based on the content of the derived data.

The intent is for knowledge discovery mechanisms to be integrated with the existing database facilities such that the integrated system appears as one system to the user. To accomplish this, it is planned to build an intermediate system between the user and the database. This intermediate system will allow the users to express their queries in terms of the structure of the problem rather than in the structure of the stored data. The rich variety of information stored as metadata will greatly enhance the browsing capabilities of the system, making it easier for users to know what kinds of information are available to meet their requirements. The intermediate system will translate the users' queries into those that can be executed by the information system.

The technical objectives established for Phase I were as follows:

Objective I

- Investigate, identify, and list oceanographic and meteorological systems that are identifiable through existing satellite sensors (visual, radiometric, synthetic aperture radar, altimeter, color scanner, and other thematic sensors).

- List the features that a particular satellite sensor exhibits that allows an analyst, using manual identification techniques, to identify specific oceanographic and meteorological systems.

- Determine and list areas of commonality in identification features for classifying specific oceanographic and meteorological systems.

- Identify existing techniques for feature detection that could be automated and incorporated into the information system.

- Investigate prediction systems that could be seamlessly integrated with the information system.

Objective II

- Recommend a generic scheme to address storage of a large volume of data, support metadata base media, and data fetches from low-speed media (optical tapes).

- Provide recommendations for integrating a system of automatic analysis tools (browse, visualization, diagnostic) as most appropriate.

The following sections address our approach to meeting the objectives, the result of our Phase I efforts, and recommendations for continued research and development for meeting the overall Phase II objective as set forth in the original solicitation.

3.0 DISCUSSION AND RESULTS

3.1 Objective I: This objective deals primarily with determining what features in satellite imagery are of interest to Navy operational oceanographers and meteorologists and the existing methodology (primarily manual) for identifying these interesting features and systems within satellite imagery. In investigating this issue, it was determined that in order to be prepared for work under Phase II, it was necessary to expand on this objective in order to understand the following:

- What information would be of interest or use in improving oceanographic or meteorological model performance if identifiable or derivable from satellite imagery now and in the future.
- Status of ongoing research and development in automated interpretation of oceanographic and meteorological satellite imagery, and prospects for the future.
- What satellite imagery is presently being used routinely by the operational community.
- The implications of the availability of some of the more exotic (SAR, Altimetry, etc.) satellite imagery on a routine basis for operational use.
- The methodology used in automated algorithms for feature recognition.

An overview of the results of our investigation into these areas follows.

Appendix A is a spread sheet which describes the manual techniques used by Navy oceanographers and meteorologists for some of the principal features and systems which they consider "interesting" in their mission of supporting Naval operations. The features selected and techniques for recognition were based on the experience of Gulf Weather's scientists and a review of NAVEDTRA 40950, Satellite Imagery Interpretation in Synoptic and

Mesoscale Meteorology, NAVEDTRA 40570, A Workbook on Tropical Clouds and Cloud Systems Observed in Satellite Imagery, Volume 1, NAVEDTRA 4097, A Workbook on Tropical Clouds and Cloud Systems Observed in Satellite Imagery, Volume II, Tropical Cyclones.

These training materials are used by the Naval Meteorology and Oceanography Command in training oceanographers, meteorologists and technicians in manual interpretation of satellite data. The manuals are quite extensive and cover a much broader field of information than presented in Appendix A. This type information should be reviewed by those involved in the development of automated features/system recognition algorithms. They not only show the features and systems that are the "things of interest" to operational users, but shows the interdependence of many features identifiable in satellite data which would indicate that algorithms could be developed which are based on subfeatures which make up larger features or systems. This type of approach works well with a metadata database system.

Generally speaking, the primary satellite data being used by operational meteorologists and oceanographers is radiometer and visual data. Some altimeter and scattermeter data are being used in the major production centers at Fleet Numerical Meteorology and Oceanography Center and the Naval Oceanographic Office in their analysis programs. SAR data available from the ERS-1 satellite system currently is not available for use in an operational sense except for sea ice analysis primarily due to processing delays which make it impractical for operational use. Color scanner data from the SeaWiFS satellite sensor system is scheduled to become available during the September-October 1994 time frame. The wide viewing capabilities and resolution which is approximately the same as the NOAA polar orbiting satellite make it a likely candidate for use by the Navy in recognizing oceanographic features such as turbidity, particularly in the near shore environment and for observing/locating atmospheric aerosols. Licensing agreements would have to be worked out with NASA/Orbital Science Corporation for use of this data. High resolution visual data shows great promise in observing and forecasting wave train/surf conditions. If a good surf forecasting models were available, a good approximation of beach front/shoreline bottom geometry could be made using this type data. DOD intelligence agencies/personnel have routine access to this type data. Navy meteorologists and oceanographers and the Navy research community should be granted access to this data. During 1998, Orbital Science Corporation, Itek Optical Systems, a Division of Litton Systems Incorporated and GDE Systems plan on launching the Eyeglass ™ Earth Imaging System, with a 1 meter resolution at nadir. This will make high resolution data available to the general public. The NASA sponsored Mission to Planet Earth, Earth Observation System (EOS) program planned for the remainder of this century and into the twenty-first century will overwhelm analysts using conventional tools, and automated algorithms will progress from the stage of a tool for assisting analysts, to become the primary and only practical means of analyzing these high volumes of data. Methodology for data storage and manipulation systems based on metadata database systems or other hybrid systems will not only fulfill the important role of storing the features of interest derived from satellite data, but will play an important part in the analysis itself.

In addition to investigating manual techniques involved in satellite analysis, a number of papers relating to on-going research and the techniques used in automated recognition of systems and features found in large digital imagery data sets were reviewed. These included the following: <u>Proceedings: Automated Interpretation of Oceanographic Satellite Images Workshop</u>, Lybannon, 1991; <u>Edge Detection Applied to Satellite Imagery of the Oceans</u>, Holyer and Peckinpaugh, 1987; <u>Processing and Analysis of Large Volumes of Satellite Derived Thermal Infra Red Data</u> , Cornillon, Gilman et al, 1987; <u>Comparative Study of Two Recent Edge Detection Algorithms Designed to Process Sea Surface Temperature Fields</u>, Cayula, Cornillon et al, 1990; <u>Contextual Pattern Recognition Applied to Cloud Detection and Identification</u>; Kittler and Parrman, 1985; <u>Toward Automated Interpretation of Satellite Imagery for Navy Shipboard Applications</u>, Peak and Tag, 1992; <u>Cloud Classification of AVHRR Imagery in Maritime Regions Using a Probablistic Neural Network</u>, Bankert, 1993; <u>Segmentation of Satellite Imagery Using Hierarchial Thresholding and Neural Networks</u>, Peak and Tag, 1994; <u>Data Mining of Multidimensional Remotely Sensed Images</u>, Cromp and Campbell, 1993 and <u>Evolution of an Intelligent Information Fusion System</u>, Campbell and Cromp, 1990.

From the review we have concluded the following:

- There are a number of automated algorithms in existence in the research community that could immediately be applied operationally for analysis of satellite data. Some manual intervention may be required with some of the algorithms at this time.

- The metadata database system which we propose for deriving, storing and manipulating features and systems derived from satellite data must be robust in its ability to utilize any feature/system recognition algorithms which may be based on a variety of techniques and are dependent on a number of differing attributes in various types of satellite data.

- The system developed must be flexible for use by a variety of users based on their "level of interest." For example, the Fleet Numerical Meteorology and Oceanography Center (FNMOC) may be interested in all meteorological and oceanographic events observable in any type satellite data whereas a shipboard meteorologist/oceanographer may only be interested in a small number of features, identifiable from satellite data available through the SMQ-11 satellite data receiver and for the very small area in which the ship or force may be operating. The FNMOC has its Cray Supercomputer and peripherals, and the shipboard operators have the TESS-3 System. The metadata database architecture planned will accommodate these operational users as well as the R&D Community.

- Feedback to the R&D Community of metadata databases on specific features/systems of interest should be arranged through the operational community. This will provide the researchers with "ground truth" databases of analyzed features similar to the database provided by NAVOCEANO to the GWC/CAST team for their Phase I efforts. These databases could then be used in evaluating new and improved algorithms.

- The U. S. Navy's environmental support interests are shifting from the blue water to the near shore environment. The metadata database system to be developed will not be area dependent. Algorithms and applications programs developed for any area of the world will be acceptable into the metadata database system.

- Cromp and Campbell indicate that NASA is planning a metadata database system for the future for handling the extensive data anticipated from the EOS program. Their development of this system carries well into the 21st century, and it is anticipated that it will do everything for everyone. The system we propose will be ready for use in two years, and will be tailored specifically for Navy needs.

3.2 Objective II: During this preliminary phase (Phase I) of the project, it has been our goal to define (as much as possible) the necessary constraints that we would apply to our metadata database development for Phase II regarding oceanographic and meteorological data storage and retrieval, specifically that derived from satellite sensors. The logical design that will evolve from this project however, will be extensible to other oceanographic and meteorological data types as well without major changes to the basic structure. And further, with some modifications to the basic design, the principle is also applicable to other disciplines where ever large and diverse data sets need to be stored, retrieved and manipulated efficiently.

Through extensive search of reference material, as well as what we have learned from prior experience, we have determined that the metadata management concept can be applied to efficiently accomplish the following:

- store/retrieve data
- optimize access to data
- manage data (track, archive, backup/restoral)
- process data
- interpret data
- classify data
- establish scalability
- establish relationships of data to users and other elements, etc.

Two aspects of our overall system design for Phase II have to be considered. First the structure of the metadata database system itself must be specified. And then secondly the attributes and the associations of the metadata itself within the system must also be specified.

First, considering the system design, to make the metadata concept realizable we have learned that we must:

- define a structure/method for how metadata are created and defined

- develop tools for metadata creation and management
- automate as much as possible the derivation of metadata
- establish a feasible way to evolve the metadata system from current legacy systems
- develop a natural way for users to view and use metadata
- develop an Application Programming Interface (API) to both general applications and the storage system
- optimize the software system for the next generation of hardware, including mixed storage media (i.e., optical and magnetic)

During Phase I of this project we have conceptually applied what we have learned from supporting other Navy research efforts utilizing the Navy Environmental Operational Nowcast System (NEONS), developed by NRL Monterey, to the problems described above. The current version of NEONS however is based on a relational model and therefore incurs certain limitations that restrict the utility of our ultimate system, particularly for extensibility and for complex applications involving the query process. Our work during Phase II will incorporate an object oriented approach. There are five primary limitations of the relational model that we need to consider that will be overcome by incorporating an object oriented model. First, for a relational system a user must first decompose information in order to store it, then recompose it every time a query is made. Second, the relational model does not differentiate between entities and relationships, everything is represented as a relationship. This makes it difficult for an uninitiated user to gain quick recognition. Third, the relational model does not allow attributes to be multi-valued, thus requiring more extensive tables. Fourth, the relational model can not implement the concept of aggregation. Aggregates are groupings of objects so that groups may be treated as single objects. Fifth, the relational model does not support the concept of generalization. Generalization allows objects to be grouped into classes and subclasses. Using generalization, we may define an inheritance hierarchy so that elements of a subclass inherit the properties of their superclasses. This results in a significant reduction in redundancy in the database, since it is not necessary to repeat the properties of the superclass in each of its subclasses. Generalization and aggregation provide a way for database systems to capture more of the semantics of the application which they are intended to model. Further benefit results from the natural gains of using object oriented programming:

- improved software quality,
- shorter development times,
- increased programmer productivity,
- and, greater reusability of code.

In addition to the overall system design considerations above, the second area of emphasis will be on the structure of the metadata itself. These considerations are just as critical as the foregoing. The metadata structure must:

- be robust,
- be fully descriptive for the area of interest,
- allow natural queries to be readily and intuitively formed,
- lend itself to automation,
- be easily extensible,
- conform to widely recognized standards,
- provide place holders for legacy metadata,
- and, result in improved performance over current systems.

To accomplish the above, and to ensure that the end-user will be able to access the data in a way that seems as natural as possible to them in terms of the problems they wish to solve, we will collaborate extensively with the end-user community to ensure proper definition of the metadata structures. This includes defining the attributes and functions that will make up the objects, as well as the classes and subclasses. Our primary effort again will be focused on metadata of satellite images, but some consideration will also be made to accommodate numerical model outputs and in situ measurements as well. Preliminary object diagrams for both image and grid data are shown later to give you some idea of the progress to date. These object models will accommodate the derived metadata objects. Much more work is needed to also take into account the user and system perspective. Also included are the functional diagrams that we evolved in support of Phase I.

To summarize, the primary goal of Objective II is to design an underlying data/knowledge management system that will:

- provide a means to capture data/knowledge extracted from some primary or low level (minimally preprocessed) data set (i.e., IR/VIS Satellite Imagery)

- accommodate data/knowledge extraction from some primary or low level (minimally preprocessed) data set by manual or automated means (i.e., manual image analysis or automated feature detection)

- store the captured data/knowledge within the system in a form easily queried such as metadata (i.e., feature *ID* is "warm eddy #123...", size, shape, location, etc.)

- provide a library of automated knowledge extraction algorithms and manual methods

- accommodate storage and retrieval of rules associated with automated algorithms and manual methods

- provide a graphical user interface (GUI) with tools for a direct user to "browse" the database and to query the database in a natural way readily interpreted within the context of oceanography and meteorology research and operations (to include remote sensing functional terminology)

- provide tools within the GUI for a direct user to conduct cross-correlated queries based on several different data sets within the database (i.e., find all images containing eddies for a region and time period where there also exists altimetry and in situ obs)

From what we have learned during Phase I, as well as our prior research efforts, we are confident that the application of the object oriented database model will not only allow us to meet the objectives of this proposal, but will make it extensible to other disciplines and to industry as well.

(THIS SPACE INTENTIONALLY LEFT BLANK)
(SEE FIGURE ON NEXT PAGE)

Figure (1) shows a high level view of the system from the perspective of Data/Knowledge Manipulation and the functional connectivity with the Knowledge Discovery Module, the Data Analysis Tools, the DATABASE-KNOWLEDGE BASE and the end-users and applications.

SATELLITE IMAGE DATA AND KNOWLEDGE INTERACTIVE SYSTEM (SIDAKIS)

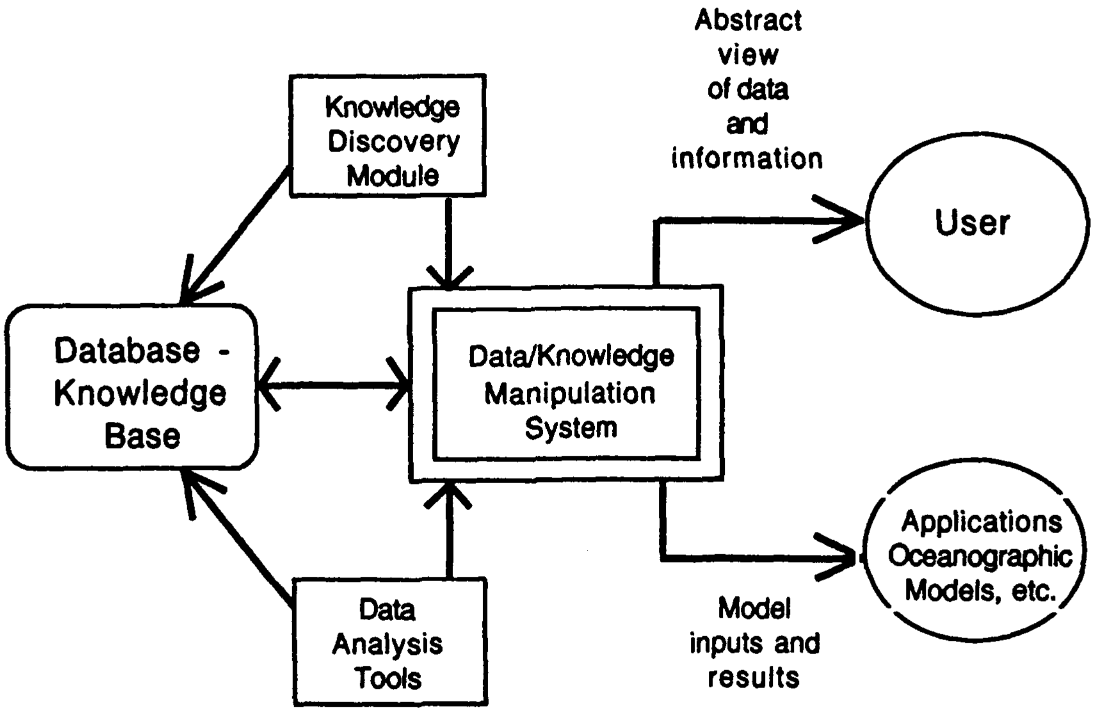
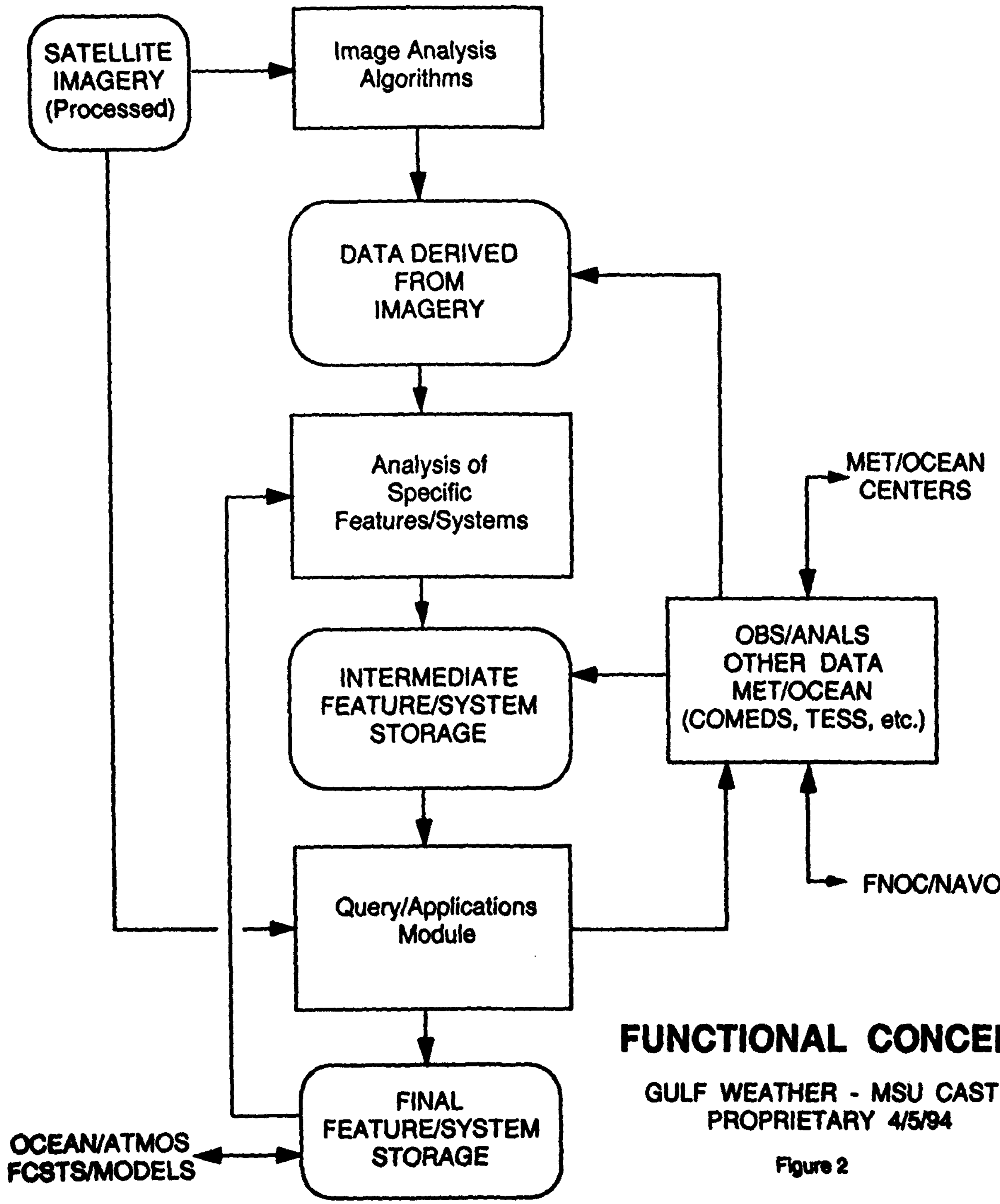


Figure 1

Figure (2) shows a high level view of the system from the perspective of the connectivity of the analysis/query/user functional modules to one another and to the underlying DATABASE - KNOWLEDGE BASE (DBKB). Components of the DBKB are shown with rounded corners. Note that a component of the DBKB falls between each of the analysis/query/user modules thus making it readily possible to either update or change any of the analysis/query/user modules with minimal impact on the rest of the system. The DBKB simply is updated with the new information.

(SEE FIGURE(2) ON NEXT PAGE

SATELLITE IMAGE
DATA AND KNOWLEDGE INTERACTIVE SYSTEM
(SIDAKIS)



FUNCTIONAL CONCEPT

GULF WEATHER - MSU CAST
PROPRIETARY 4/5/94

Figure 2

OBJECT DATABASES: MERGER OF TWO TECHNOLOGIES

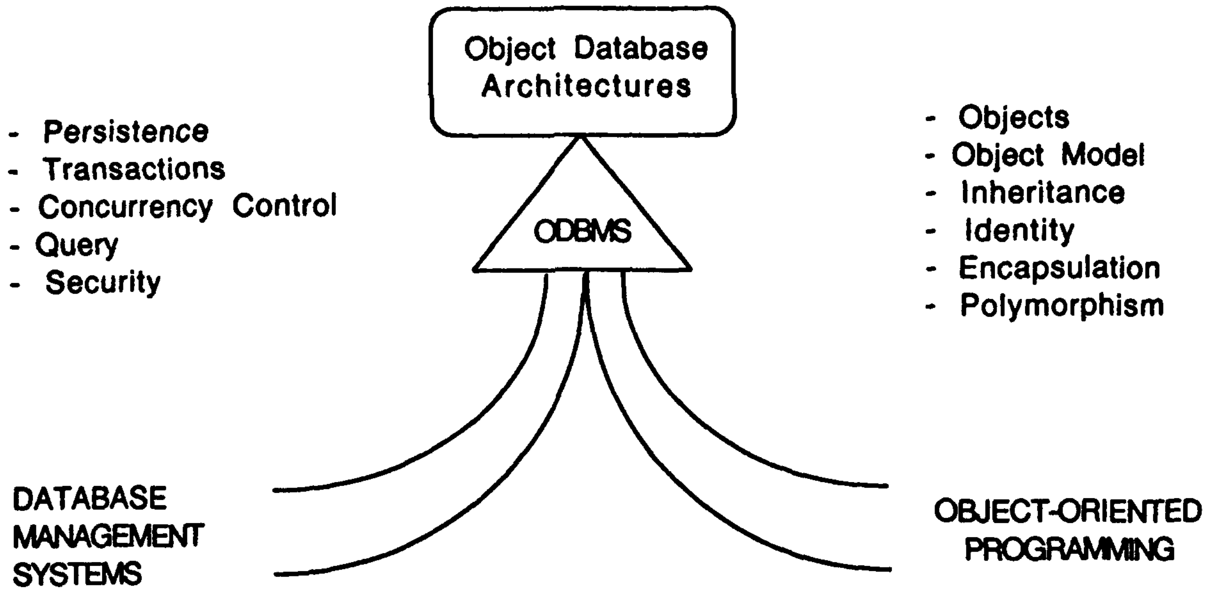


Figure 3

The Object-Oriented Database Management System (ODBMS) combines the best attributes of both the Database Management System and Object-Oriented Programming (see figure 3). The complexity of database management systems shows up not only in the software that manipulate the data, but also in the data themselves. Object oriented databases address both the source of complexity by including facilities to manage the software-engineering process (e.g., data abstraction and inheritance) and features for capturing more directly some of the interconnections and constraints in the data (e.g., properties, relationships and complex objects).

The diagrams in figures (4) and (5) represent the components of an image and its relationships with satellites (see figure 4), and grid data and its relationship with the grid model (see figure 5). Object classes are represented as rectangles in the diagram, with the name of the object class appearing in the box at the top of the rectangle. The diamond shaped boxes represent relationships between the object classes, with the relationship being read from left to right or from top to bottom in the diagram. Each object class represents a class of objects where each object may be manipulated by the database user as a single entity. Thus the scientists may manipulate an image as a single entity, a set of images as a single entity, etc., and the same for grid data, depending on the needs of their application.

Referring to figure (4), an image consists of one or more lines, where each line has a time stamp and each image has a start time. The start time of an image is the time stamp of the first line in that image. One or more samples may be taken from a line. Every image is associated with a particular location, and many images may be associated with the same location. Each image has a projection, with the projection being one of the five types shown in the diagram (curvilinear, spherical, etc.). A satellite contains one or more sensors, and each sensor has one or more channels. Each channel is sensitive to a particular band, and each sensor is identified as a particular sensor type. For example, AVHRR is a scanning radiometer. A satellite may produce a number of images. We have not yet illustrated the concept of having sets of images such as a time series of images. We intend to represent the various ways in which images may be aggregated.

In figure (5) a grid data set consists of one or more grid fields, with each grid field consisting of one or more grid points. A particular grid data set is the result of a run of a particular grid model version. A grid field measures a particular grid parameter at a particular level at a given time. A grid data set has a particular grid geometry associated with it. There are two subclasses of the grid geometry class: registered geometries and spectral geometries. A registered geometry has a projection, with the projection being one of the five types shown in the diagram (curvilinear, spherical, etc.).

(THIS SPACE INTENTIONALLY LEFT BLANK)
(SEE FULL PAGE FIGURES NEXT TWO PAGES)

OBJECT DIAGRAM FOR IMAGE DATA

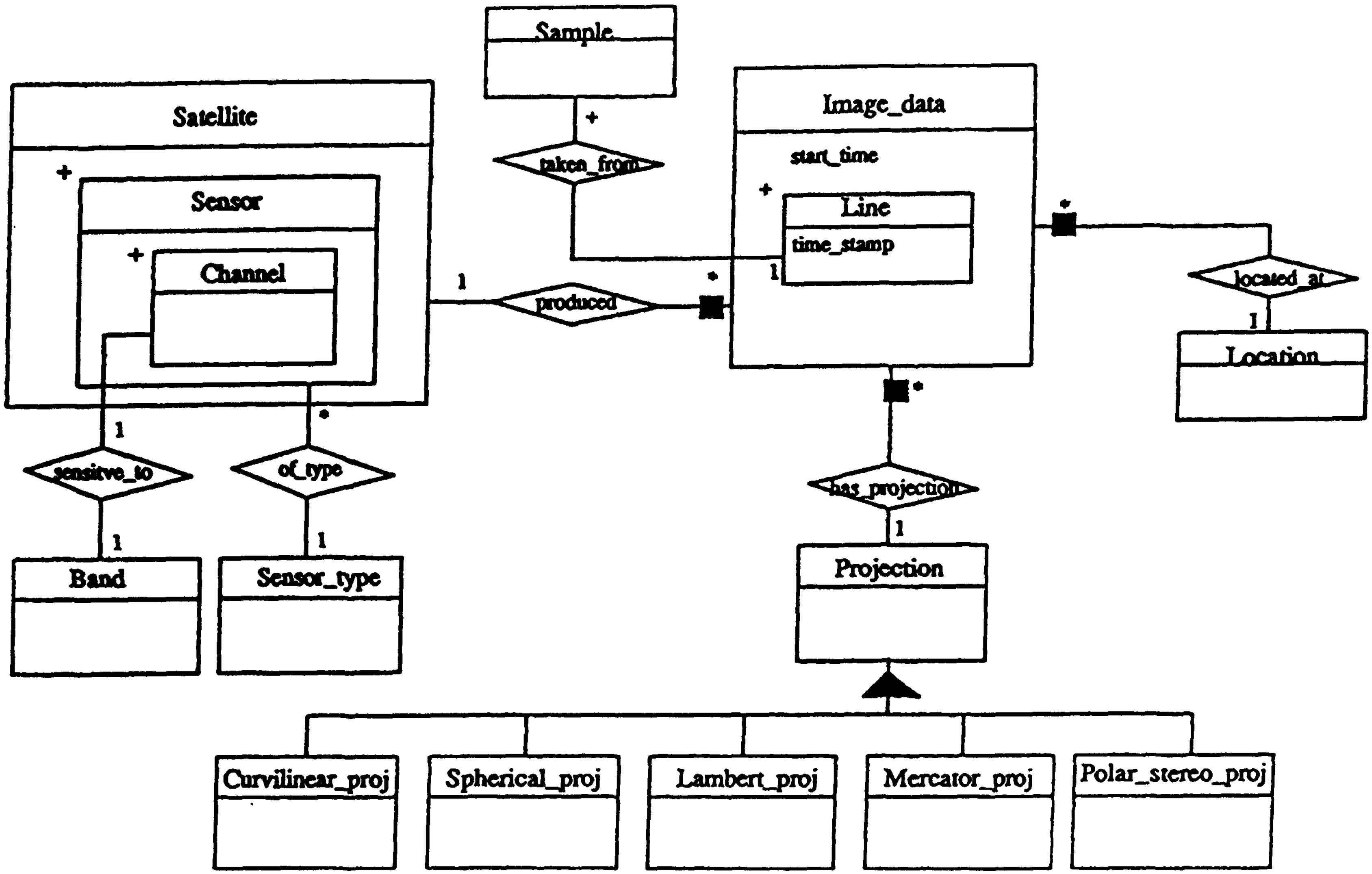


Figure 4

OBJECT DIAGRAM FROM GRID DATA

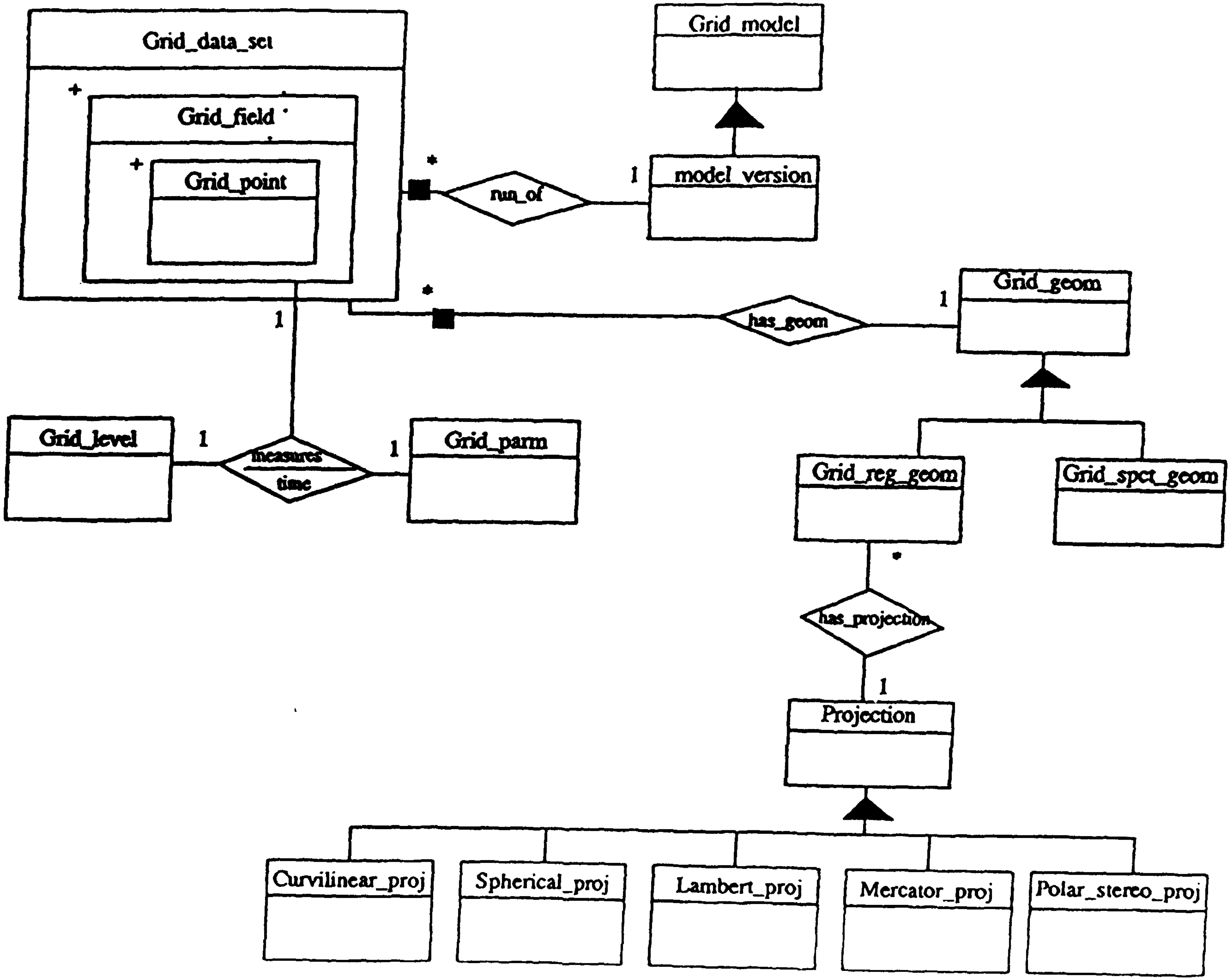


Figure 5

4.0 DEMONSTRATION MODEL FOR A METADATA DATABASE SYSTEM

4.1 Discussion

The GWC/CAST research team felt that a demonstration system showing a simplified metadata database system with a capability for manipulating automatically derived satellite data would strengthen our arguments for obtaining a Phase II contract, particularly since the overall objective of Phase II is to develop a complete end-to-end system.

During our investigations of the operational uses of meteorological and oceanographic satellite data we discovered that the Naval Oceanographic Office had developed a database of manually analyzed AVHRR data for the Gulf Stream and Loop Current for the period 1990 through 1993. We felt this data might be quite useful in evaluating automated algorithms for interpreting oceanographic satellite data in the Atlantic and Gulf of Mexico. We also felt that it might help in demonstrating the capabilities of a metadata database system for applying automated feature derivation algorithms, and for manipulating and storing the data and derived products.

In the demonstration model we assumed that the NAVOCEANO ocean analysis is a metadata database of features derived through the use of an automated algorithm. The actual satellite data, AVHRR, for the time frame of the test, was stored in a database and was available to the operator of the demonstration system for purposes of evaluating, to some extent, the analysis, but primarily to show the use of satellite imagery in the system. The first set of queries/applications used randomly selected data for the position of the fronts and eddies over the entire period of the database. the second set used data for the month of May 1993, chosen primarily because it represented what appeared to be one of the most cloud free months in the analyzed database.

Wind information from two NOAA moored meteorological/oceanographic buoys off Cape Hatterus and Cape May were stored in what would, in a completed version of the system, be the observations/analysis section of the metadata database system. In an operational scenario this type information would be available over weather/oceanographic circuits. The size of this database was kept small to make the demonstration model fairly simple. A series of simple queries/applications relating dependent variables to independent variables were developed and stored in the query/applications metadata database. The primary rationale for the demonstration was to show an operating metadata database system in a simplified fashion. Results of the queries and applications were not considered important, particularly when considering the short time frames used in the metadata databases.

- **Dependent variables considered were:**

  Position (latitude, longitude) of fronts

  Curvature of fronts

  Central location (latitude, longitude) of eddies

  Rotation speed of eddies

  Major/Minor axis of eddies

  Speed/Director of movement of eddies

  Temperature contrast across fronts

  Temperature contrast across eddie edges

  Type (warm/cold) of eddies

  Central temperature of eddies

- **Independent variables considered were:**

  Bathmetry

  Wind stress (derived from winds)

  Time

  Latitude

A review of weather charts, which would normally be available in the observations/analysis module for the test period revealed that the eastern seaboard of the U. S., was undergoing a typical spring transition. Weak polar fronts were moving through the area approximately every three to four days and dissipating off-shore. High pressure ridging eastward off the east coast behind the front would dominate for a day or two, and as the front weakened the Bermuda high would ridge westward for a day or two. Basically, as far as describing the weather situation as it might be expected to dynamically influence any oceanographic parameters, it could be described as basically negligible.

Although the demonstration was not expected to provide any significant answers as to the behavior of the Atlantic fronts and eddies, it did show that interesting information could be derived from such a system. Once again, we caution the use of any of the data retrieved as being indicative of long term behavior of the Atlantic front and eddies. But, it does show that the system with properly developed queries and applications could transform satellite imagery through automated algorithms into useful data for interfacing with forecast models and applications.

4.2 Results of the Demonstration

The following answers were provided to the queries/applications applied to the analyzed/simulated derived oceanographic database.

TEST 1.

Overall

The frequency of cloud-free observations of any section of the Gulf Stream and eddies is: once every two days in spring, every three days in summer, four days in fall and five days in winter. Two thirds of the observable segments were less than 100 km long.

North Wall

The position of the north wall is not normally distributed around a mean position. Instead, it has a preferred modal position. That position is 35.4 N at 75W, 37.8N at 70W, 39.0N at 65W, and 40.0N at 60W. The median speed of the front is 10 cm/s at 50 and 70 degrees West longitude and 20 cm/s at 60W. The temperature contrast across the front is maximum in winter off the U. S. Coast (about 10C). The minimum contrast is offshore during summer.

Eddies

Nearly circular eddies last the longest. Elliptical eddies tend to break apart into smaller ones, or get reabsorbed. Larger eddies and more elliptical eddies move and rotate more than small ones. Highly elliptical eddies with the major axis north-south move the most. Eddies with the strongest temperature contrast occur in the west. The influence of water depth in formation and path of eddies is weak.

Test 2 (May 1993)

The Northern Edge

The Gulf Stream regions were visible through clouds in satellite images about one day of two in May 1993. A total of 200 edge segments were recorded. Most segments (2/3) were less than 200 km long. This is one of the highest visibility rates over the four year period (1990-1993).

The maximum, minimum and modal positions of the Gulf Stream were:

Ref. Long.	Max. Lat.	Min. Lat.	Modal Position
50W	41.8	40.9	41.8
55	42.0	39.0	41.8
60	41.4	39.0	39.2
65	41.2	38.0	28.1
70	38.2	37.3	39.6
75	38.5	34.8	35.1

During the month of May, the edge migrated north and south at speeds between 10 and 20 cm/sec.

Eddies

One cold-core eddy was observed in May 1993. At the beginning of the month it was located at 39N-64.6W. It moved to 36N-66W by the end of the month. The eddy was approximately three degrees colder than the surrounding water. The diameter was about 60 km, and was rotating at about 40 cm/sec. It's mean speed over the month was 15 cm/sec to the southwest.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the Phase I research, the Gulf Weather Corporation/Center for Air and Sea Technology team has reached the following conclusions:

- The present methodology, primarily manual, for analyzing and interpreting oceanographic and meteorological satellite data is cumbersome and rapidly being overwhelmed by the volume of data available and the increasing requirements for use of remotely sensed data from satellites as inputs to oceanographic and meteorological forecast models and for fleet operational support applications.

- NASA's Mission to Planet Earth, the Earth Observing System (EOS) program and other national and international programs will rapidly increase the availability of environmental satellite data over the next ten years.

- The only practical solution for the Navy, particularly in view of ever decreasing manpower levels, is to intensify research and development on automated systems for satellite data interpretation.

- There are some algorithms for automated interpretation available today and others under development that show promise of success.

- A user friendly automated system that requires little knowledge of the satellite data sensors, formats, etc., the algorithms and the science/background of the inquiries or applications by the operator for assessing and using oceanographic and meteorological satellite data is required. The metadata database system discussed in this report can satisfy this requirement.

5.2 Recommendations

The following recommendations are provided:

- The Navy continue its active program of automated algorithm development for interpreting oceanographic and meteorological satellite data.

- The metadata database system as outlined in this report be developed as the complete end-to-end system for a unified information structure for a system of tools and methodology for the automated interpretation of oceanographic and meteorological satellite imagery.

REFERENCES

Bankert, Richard L., 1993: Cloud Classification of AVHRR Imagery in Maritime Regions Using a Probabilistic Neural Network, U.S. Naval Research Laboratory, Monterey, CA. Submitted to *Journal of Applied Meteorology*, December 1993.

Campbell, William J. and Robert F. Cromp, 1990: Evolution of an Intelligent Information Fusion System, Photogrammetric Engineering and Remote Sensing, Vol. 56, No. 6, pp. 867-870.

Cayula, Jean Francois and Peter Cornillion, 1992: Edge Detection Algorithm for SSI Images, AMS, *J. Atmospheric and Ocean Technology*, Volume 9, pp. 67-80.

Cornillion, Peter, Craig Gillman, Lothar Stramma, Otis Brown, Robert Evans and James Brown, 1987: Processing and Analysis of Large Volumes of Satellite Derived Data, *J. Geophysical Research*, Volume 92, No. C12, pp. 12,993-13,002.

Cromp, Robert F. and William J. Campbell, 1994: Data Mining of Multidimensional Remotely Sensed Images, NASA/Goddard Space Flight Center, Greenbelt, MD, 11 Holyer, Ronald J. and Sarah H. Peckinpaugh, 1988: Edge Detection Applied to Satellite Imagery of the Oceans, IEEE Transactions on Geoscience and Remote Sensing, Vol. 27, No. 1, pp. 46-56.

Kittler, Josef and David Pairman, 1985: Contextual Pattern Recognition Applied to Cloud Detection and Identification, IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-23, No. 6, pp. 855-863.

Lybanon, Matthew, 1991: Proceedings: Automated Interpretation of Oceanographic Satellite Images Workshop, 1991; NOARL, Stennis Space Center, SP001: 321:91, 226 pp.

Peak, James E. and Paul M. Tag, 1992: Toward Automated Interpretation for Navy Shipboard Applications, Bulletine of AMS, Vol. 73, No. 7, pp. 995-1,008.

Peak, James E. and Paul M. Tag, 1992: Segmentation of Satellite Imagery Using Hierarchical Thresholding and Neural Networks, Accepted for Publication AMS, *J. of Applied Meteorology*, 35 pp.

APPENDIX A

METEOROLOGICAL AND OCEANOGRPAHIC FEATURES IDENTIFIABLE IN THERMAL AND/OR VISUAL SATELLITE DATA

METEOROLOGICAL AND OCEANOGRAPHIC FEATURES IDENTIFIABLE IN THERMAL AND/OR VISUAL SATELLITE DATA

1. CLOUDS

Type	Size	Shape	Shadow	Time & Texture	Comments
a. High Level Cirrus (CI)	Mesoscale and larger	Defined by generating physical processes. Elongated streaks, ill-defined, wispy or fibrous edges	May cast shadow lower cloud decks	Visual: Fibrous/Wispy to minimal texture IR: Minimal texture resulting from variations in cloud thickness, gray to white depending on thickness	
Cirrostratus (CS)	Generally large	Same as CI above	Same as CI above	Visual: No texture, uniform white. IR: No texture, white.	Cirrostratus is thick stratus occurring in thick sheets, with wispy cirrus near down-stream edges. Often some texture may be seer in large CS sheets which is usually the result of gravity waves and indicative of turbulence.
Cirrocumulus (CC)	Mesoscale an larger	Same as CI above	Same as CI above	Visual IR: signature same as CI more or less extensive sheets, consisting of very small elements in the form of grains or ripples. May often show as one or two systems undulations. May also occur in patches in the shape of lenses or almonds, often very elongated and usually well-defined outlines	

b. Mid-Level Clouds Altostratus (AS)/ Altocumulus (AC)	Generally larger than mesoscale, dependent on effect of physical processes.	Defined by physical processes. Edges well defined. Mountain ranges may induce gravity wave pattern in cloud shield.	May cast shadow on lower deck.	Visual: AS-smooth, no texture, white IR: Minimal to no texture, to white	Difficult to recognize in satellite data. Hidden by high cloud. Some signature as CS clouds
c. Low Level Clouds Stratus (ST)/Fog (F)	Generally local phenomena dependent on generating process.	Defined by terrain and generating processes. Sharp edges.	No shadow	Visual: Smooth, minimal texture; gray to white IR: Smooth, no texture gray to invisible with respect to surrounding surfaces.	Stratus and fog indistinguishable from each other.
Stratocumulus (SC)	General mesoscale or larger, dependent on extent of generating physical process.	Defined by generating physical processes. Terrain influences shape, edges generally not sharp.	Casts minimal discernable shadow if any	Visual: Lumpy, globular clouds, white	
d. Convective Clouds Cumulus (CU), Towering Cumulus (TCU)	Individual clouds are mesoscale or less	Individual clouds are circular, but may be organized into lines or streets. Edges, very sharp. Development influenced by terrain and physical processes.	May cast individual shadows on lower cloud decks dependent upon vertical extent of cumulus cloud.	Visual: Very lumpy,. globular clouds, bright white. IR: Moderate texture, white, dependent on enhancement scheme.	
Cumulonimbus (CB)	Individual clouds are mesoscale	Individual clouds are circular except for cirrus anvil blown downstream from the preleus if winds at cloud top level are strong. Edge very sharp except at cirrus anvil which is fibrous and wispy.	May cast strong shadow on lower decks.	Visual: Very lumpy, globular clouds, very bright white. IR: Strong texture, bright white, dependent upon enhancement scheme.	

e. **Orographic Cloud (Wave Cloud)**	Mesoscale	Parallel bands more or less evenly spaced	Not prominent	<u>Visual</u>: Texture is banded, gray in tone, but sometimes white <u>IR</u>: A little texture on bands. Gray to white.	Bands uniformly spaced, parallel to mountain range. May appear at all levels--Cirrus, altocumulus or stratocumulus.

2. LOW LEVEL AND SURFACE DYNAMIC FEATURES

a. Extratropical Low Pressure Center

Pattern recognition is the primary technique for identifying extratropical lows. Junker and Haller (1980) developed a pattern recognition correlation technique for estimating central pressures vs. low pressure as center develops from open wave pattern through various stages to maturity. Center selection is difficult in early stages, but becomes apparent with development of a closed system. Surface lows usually found under strongest positive vorticity advection (PVA) in early stages of development (PVA discussed later).

b. Cold Fronts

Typically the easiest front to diagnose from satellite imagery. Convective clouds in lines along leading edge of cold air are common depending on the stability of warm air mass and upper air dynamic support. Low level northwesterly winds in the wake of cold front are evidenced by any of the cloud elements described in previous section. Stratocumulus in straits are evidence in continental areas and open cellular cumulus in straits over open ocean areas. Rope cloud, long line of cumulus generated by low level convergence of the observed over ocean. Cold frontal cloud bands may be 50 to 100 miles wide, thus placement of front may be difficult. If cumuliform clouds observed front placed to rear of low level cloud band. If front inactive, place front toward leading edge of generally stratiform cloud deck. Exact position may be determined by line of cumulus in otherwise stable cloud area.

c. Warm Fronts

Very difficult to identify from satellite imagery. Mid-High level clouds obscure low level features used in identifying/placement of warm front. Position of warm front often accurately defined away from the wave crest when the high overcast begins to thin.

d. Tropical Cyclones

Tropical cyclones are likely the most recognized weather pattern in satellite imagery, particularly in the latter or mature stages of development. During the early stages of development, characterized by a curved band pattern, and center location is difficult. As the storm intensifies, the center or "eye" becomes enclosed and one can observe an open center or "eye". At times high level clouds may obliterate the "eye." Once an enclosed "eye" is formed, location from satellite imagery is quite simple. Intensity estimates can be made using the Dvorak developed T-number estimate from cloud formation shapes. In fully developed storms with a well defined eye, some indications in storm intensity can be made by comparing the warmer temperature at the center or "eye" with the temperature in the clouds (wall clouds) surrounding the "eye."

3. NEAR SHORE/COASTAL ZONE EFFECTS

a. Wind Flow Associated with Sea Breeze

The sea breeze is recognizable in visual satellite data by the distribution of low level clouds along the coastline of major water bodies. The pattern consists of a narrow cloud-free region along the immediate coast corresponding to a directional onshore low level flow. Further inland, convective cloudiness will form in an area of upward motion. Offshore in the area of downward vertical motion, there will usually be an area of relatively clear skies.

Off the East Coast is summer warm northerly flow forms advection fog in the cold water north of the Gulf Stream. The offshore component along with downward vertical motion is responsible for an area of dry air just offshore. This can be seen readily in satellite imagery. As the circulation breaks down near the end of the day, the advection fog moves inland.

b. Low Level Flow Associated with Island Effects

The interruption of large areas of fog, stratus, or Stratocumulus by islands often given a clue to the low level wind direction. Low level clouds are usually advected along by the low-level winds and accumulate on the upwind side of the island. Clouds will be absent for a distance in the downward side but reform further downstream.

c. Low Level Flow Associated with Orographic Effects

Terrain induced cloudiness caused by upslope flow will indicate the direction of low level flow. Wave clouds in low level stratocumulus may form over some terrain with the direction of flow at right angle to the wave clouds. Valleys that converge to a narrow or closed end provide a natural low level convergence zone and as such stimulate the production of low and mid clouds. Rapid convection may be associated with these low level convergence zones. Convective cells move along the valley. Outflow of drier air from the interior, common with night time sea breeze effect. produces clearing through coastal inlets and well offshore.

4. MID AND UPPER AIR DYNAMIC FEATURES

Dynamic and physical processes in the upper atmosphere can be identified manually in satellite imagery through pattern recognition. In many cases, the identification of dynamic features requires the use of animated imagery. Cloud structures in static imagery bear a close relationship to dynamic features. Thus, the historical library aspects of a metadata database system could be used for computerized animation of such dynamic features as the rapidly moving cloud patterns associated with the jet stream. In manual processes, the analyst also uses upper air analysis and prognostic charts as well as any local observations in verifying the dynamic processes of interest. NAVEDTRA 40950, Satellite Interpretation in Synoptic and Mesoscale Meteorology describes the manual processes for identifying such dynamic features as the jet stream, upper air troughs and ridges and vorticity maxima.

5. OCEANOGRAPHIC FEATURES

a. Ocean Fronts

The classical definition of the leading edge of an ocean front is the 15°C isotherm at 200 meters depth. Using satellite data to determine frontal positions requires a different definition, usually the leading edge of the tightest temperature gradient is the boundary. In visual imagery, the front may be associated with areas of banded cumulus clouds of increased height forming downwind of the colder water. With color scanner data there is normally a color change across the frontal zone. In altimetry data, the warmer water would be indicated by increased height across the frontal zone. With SAR data, there is a noticeable difference in the surface roughness, the warmer water appearing more rough than the colder water.

b. Ocean Eddies

Basically, the same rule apply for recognition of ocean eddies as apply to ocean frontal zones. Ocean eddies associated with frontal zones are generally circular or elliptical. Size is normally of the order of 100 Km. They may be identified as having a warmer or cooler surface temperature at a core surrounded by a temperature contrast (gradient) boundary. In visual satellite imagery, the warm core eddy may be recognized by a cumulus cloud mass over the warmer center. Cold core eddies may be associated with lower level clouds. There is normally a color change recognizable in color scanner data associated with the eddy footprint. Altimetry data is excellent for locating center positions of eddies since there is a change in height signal from low to high and back to low again (warm eddy) or high to low and back to high again (cold eddy) when the altimeter ground track passes near the eddy center. SAR data is also extremely effective for locating eddies since there is a distinctive surface roughness change associated with the eddies (rougher over warmer water as compared to cooler water).

c. Sea State

Sea state measurements are made through a averaging process using scatterometer or altimetry data. Manual interpretation of this data would be difficult. SAR data can also be used by estimating sea conditions correlated to surface roughness.

d. Surf Lines

Very high resolution visual imagery data is becoming one method for estimating surf lines and surf conditions. Other averaging techniques from altimetry, scatterometer and SAR do not provide enough resolution yet to be useful in an operational since.